Draft

Applying Science and Technology Roadmapping in Environmental Management

Special note for this draft

This discussion draft is intended to generate an exchange of ideas about the role of science and technology roadmapping within EM. This draft will be distributed for review and comment to the EM groups that have a stake in why and how roadmapping is conducted. Feedback will be incorporated into the final document . This draft is also intended as a reference for current EM science and technology roadmapping efforts, to validate the roadmapping methods and generate additional examples for possible inclusion before the document is finalized.

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Table of Contents

Acronyms

CSTR	Continuous Stirred Reactor
CWVZ	Complex-wide Vadose Zone
D&D	decontamination and decommissioning
DNFSB	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
FFA/STP	Federal Facilities Agreement/Site Treatment Plan
GW/VZ	Ground Water/Vadose Zone
EM	Environmental Management
ES&H	Environment, Safety and Health
HLW	High-Level Waste
IPABS	Integrated Planning, Accountability, and Budgeting System
ITP	In-Tank Precipitation
MST	Monosodium Titanate
NAS	National Academy of Science
NEPA	National Environmental Policy Act
OST	Office of Science and Technology
R&D	research and development
RIM	Robotics and Intelligent machines
SRS	Savannah River Site
SRTC	Savannah River Technology Center
STCG	Site Technology Coordination Group
TCLP	toxicity characterization leaching procedure
TSD	treatment, storage, and/or disposal
TRU	transuranic

Applying Science and Technology Roadmapping in Environmental Management

INTRODUCTION

This document provides insight (as opposed to strict guidance) as to the value, fundamental considerations, and available techniques for the application of ***science and technology roadmapping***[1] within DOE's ***Environmental Management (EM) programs***. There are two intended audiences and the document is structured in two major sections. Section I is designed to assist managers who are considering whether to roadmap a particular project, program area, or cleanup problem. Section II and Appendix A are designed to assist roadmapping practitioners and participants.

Roadmapping began in private industry as a market analysis and product planning tool. It has been adopted by various government agencies to assist in planning of research programs. It is a highly effective way to forecast critical new technology development requirements, and a valuable planning tool for decision-making. The roadmapping process clarifies critical ***missions***, applies collaborative realism to solve complex problems, and builds consensus to address near- and long-term ***science and technology*** needs.

The successful use of science and technology roadmapping within EM requires consistency of purpose along with significant flexibility of application to accommodate variations between different projects and programs. Many reports of roadmapping efforts have been reviewed during the preparation of this document. These reports are listed in the References. The reports showed a commonality of certain essential roadmapping attributes and process steps. These essential elements are presented, along with examples and sample techniques, to allow each EM roadmapping effort to be tailored as needed while maintaining a core consistency for all EM roadmaps.

[1] Key terms are indicated in bold italics on first use in the text, and are defined in the Glossary.

SECTION I - TO ROADMAP OR NOT?

What is Roadmapping and What Does it Accomplish?

Roadmapping is a disciplined, consensus-building, analysis, solution development, and decision-making methodology that supports strategic programmatic and project planning. Roadmap preparation focuses all parties on the needs, risk-reduction alternatives, desired end-states, and the paths that will lead to efficient and timely resource investment.

Roadmapping organizes and focuses a team or teams of people on a specific mission in which the substance (problem & needs) and directions (solutions) for an integrated development activity are determined. It brings the problem holder and the developers of technology solutions together to understand the process or steps required to reach predefined end points. Roadmapping is comprehensive, considers the impacts of all interfaces of the overall system and identifies the key elements and functions that must be integrated in a selected pathway to achieve a timely and successful end point. The products from roadmapping are living documentation of the consensus of the roadmap team concerning an acceptable course of prioritized actions. The roadmapping process necessarily must be formulated and adapted to each specific situation and designed to reconcile divergent opinions and goals into a cohesive, integrated and cooperative team consensus.

Roadmapping links technology development to program and project visions, missions, and goals. It focuses needed technical support to the baseline and to backup alternatives where the probability of success is low (high uncertainty) and the consequences of failure are relatively high (high programmatic risk). Emphasis is on areas where the investments are large, the return on investments is high, and the timing is crucial for solving important cleanup problems.

Value of Roadmapping

Science and technology roadmapping provides several benefits to EM at both the program and the project levels:

- Clearly defines the technical risks associated with the project or program baseline
- Develops a vision and consensus among science and technology users, providers and management about the capabilities needed to most effectively accomplish baselines and the knowledge and technologies required to satisfy those needs
- Develops a consensus forecast among science and technology users and management for developments in targeted areas
- Provides a framework to plan and coordinate science and technology developments within a project or program, to accomplish
  - Reduction in life-cycle costs (avoided costs, cost savings, schedule reduction)
  - Reduction in programmatic risks (probability of failure times consequence of failure)
  - Reduction in public and worker health and safety risks
  - Research program relevancy to EM user near-term (2-5 years), intermediate-term (5-10 years) and long-term (10-20 years) needs.

Workshops held during the roadmapping process provide a forum for individuals with responsibility or expertise in different disciplines to come together to increase the collective knowledge base through open dialogue and feedback and:

- Understand site baselines and requirements
- Codify knowledge and technology needs
- Compare these needs to the current state of science and technology
- Identify gaps and shortfalls between the current and needed states
- Develop defensible alternatives for meeting shortfalls, while also identifying ways to leverage R&D investments through coordination of research activities
- Develop schedules and priorities to maximize benefits from scarce resources
- Synthesize understanding into a conceptual path forward for R&D activities.

Types of Roadmaps

Roadmapping is a general term that takes a number of specific forms when applied in industry and government. ***Industry technology roadmaps*** assess and extrapolate the direction of market demand for an area of technology, then identify R&D strategies to meet that demand. ***Critical or emerging technology*** roadmaps are used in both industry and government to plan the development of core capabilities for an area of technology with broad application. The Department of Energy has developed critical/emerging technology roadmaps for computer simulation and robotics/intelligent machines. DOE has also employed ***issues-oriented roadmaps*** to assess pathways to ensure regulatory compliance.

Product roadmaps are tools used by individual companies to identify the technical opportunities and risks associated with development of a specific application. Within EM, the focus is on solving specific cleanup problems. A modified version of the product roadmap, a science and technology roadmap, was found to have the greatest application to EM.

Technology is defined in The American Heritage Dictionary as “The application of science…” Within EM, science and technology roadmapping includes planning for scientific research and engineering development, with the end goal of cleanup and stewardship mission application. As a collaborative process for defining an R&D strategy, roadmapping:

- Identifies what to do, when to do it, and why it needs to be done, leading to consensus on priorities and path forward, but
- Does *not* identify who will do it, where to do it, or how[2] to do it.

Science and Technology Roadmaps

Science and technology roadmapping focuses on the knowledge and technology needs of a single program or project, and describes how different technologies should be developed to support those needs. Typically, the roadmap includes plans to select and develop technology alternatives for each application. The implication is that research and development will only take place when there is a predefined, direct application, for example, “mission pull.” Pursuant to the requirements of the EM Research and Development Program Plan, all science and technology roadmapping within EM is needs driven, or “mission pull.”

[2] A science and technology roadmap specifies R&D development paths, but not how those paths are implemented.

Within EM, there are two primary types of science and technology roadmaps.[3] The *program-level science and technology roadmap* provides support to an EM program; multiple, related EM projects; or a common, broad problem area. The second type, the *project-level science and technology roadmap* provides support to a single EM cleanup project. Although this document treats the two types as distinct, in practice they should be viewed as a continuum: the more general the cleanup problem, the more the *program-level* applies, the more specific the cleanup problem, the more the *project-level* applies. Table 1 denotes the primary differences between program-level and project-level roadmaps.

Purpose of Program-Level Science and Technology Roadmapping

Program-level roadmapping establishes a consensus on the intermediate-term (5–10 year) and long-term (10–20 year) general R&D. During program-level roadmapping, specific project science and technology requests are assessed to establish general needs for technical capabilities. The general needs form the basis for the general R&D agenda. For each general need that is identified, explicit capability improvement targets and potential affected projects are established to provide a schedule for R&D progress aligned with opportunities to use R&D results. The value of each capability

Table 1. Comparison of Program-Level and Project-Level roadmapping

Science and Technology Roadmapping		
Attribute	Program-Level	Project-Level
Planning Linkage	• Strategic plans, goals, and statement	• Project baseline • Disposition maps • Program-level roadmaps • Specific solutions to specific needs
Timeframe	• Five to twenty years or more (usually divided into 3 or more phases)	• Duration of the project concept through design phases (usually less than 5 years)
Needs Basis	• Generalized needs and goals of the program	• Specific explicit needs from project that are related to specific project decision points
Measures	• Improvement opportunities - Contribution to mission & vision for reducing costs, schedules and program risks and/or enabling methods to accomplish mission	• Technical risk mitigation - Gap identification and mitigation; delivery of enabling or alternative technologies and data • Effectiveness of specific support activities to reduce project costs, schedules, and ES&H impacts
Goals and Targets	• Typically percent improvements of general capabilities for each phase of roadmap	• Specific capability usually with clear functional & operational requirements, end states and selected alternatives
Recommended R&D Activities	• Typically multi-year tasks with emphasis on new theories, alternative technologies, and other needed major breakthroughs	• Typically short duration tasks focused on lab/bench-scale experiments and engineering scale tests answering specific needs for information and testing of alternatives to support project decisions or confirmation of baseline technologies

[3] The EM R&D Program Plan identifies three levels of roadmapping within EM: a multiprogram-level roadmap (the EM R&D Program Plan), program-level roadmaps (Problem Areas), and project-level roadmaps. For simplicity, this document does not differentiate between multiprogram and program-level roadmapping, which have similar purposes and use similar techniques.

improvement target is estimated in terms of project impacts to guide prioritization and resource allocation. The primary driver is to produce science-based technology improvements.

The Hanford Ground Water/Vadose Zone (GW/VZ) Roadmap is an example of an EM program-level roadmap because it supports multiple EM projects at the Hanford site. Such roadmaps will also identify interfaces to other relevant program roadmaps, e.g. the Long-Term Stewardship Roadmap.

Purpose of Project-Level Science and Technology Roadmapping

Project-level roadmapping identifies and mitigates technical risk in the project baseline. Specific areas of technical uncertainty are identified; including areas in which concepts are unproven or scaling knowledge is lacking. The goal is to identify and schedule R&D activities so that all proofs-of-concept are completed by the end of the pre-conceptual design phase[4], and sufficient engineering knowledge on process parameters and scaling is available to complete the conceptual design. Thus, the roadmapping process synchronizes facility engineering with R&D.

Project-level roadmaps are required to define the end user needs and opportunities for science and technology projects to assist in fulfilling project requirements. They should be used as tools to augment the EM planning process and reflect site baselines, project milestone schedules, disposition maps, and other IPABS planning data and systems. Per the EM R&D Program Plan, it is expected that there will be an interactive process between the end users and R&D community which will improve the overall quality of EM planning. These project-level plans should reflect the life cycle technical needs of the project (and when applicable, considerations for D&D and long-term stewardship).

The Savannah River Site high-level waste salt processing alternatives (In-Tank Precipitation Alternatives) roadmaps are examples of EM project-level roadmaps.

Relationship between Program- and Project-Level Roadmapping

Program-level science and technology roadmapping sets the general direction of science and technology development to support a group of related projects. In this role, the program level roadmap plans for research and proof-testing of technical advances *prior to* the technology selection phase (pre-conceptual design phase) of the individual projects. Thus, the program-level science and technology roadmap provides more and better options.

Project-level science and technology roadmapping assesses the options available *at the time of planning* based on their maturity and benefit. The additional research, development, and demonstrations needed to tailor each technology to the project-specific requirements also are identified in a project-level roadmap.

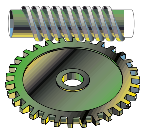
Because projects typically start at different times, the program-level roadmap usually maps out development in phases. The end dates of each phase are scheduled for completion just prior to the start of pre-conceptual design of key projects or groups of projects. This coordination provides a smooth transition from developing science-based technology improvements to engineering the application of those technology improvements to specific projects.

[4] Pre-conceptual design may be considered as the activities leading up to approval for conceptual design, and conceptual design as the activities up to approval to begin project execution, as described in DOE Order 430.1A, “Life Cycle Asset Management.”

Key Principles of Roadmapping

EM science and technology roadmapping is:

Needs-Driven



A. Needs-driven

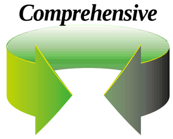
- Is owned by the cleanup project or program
- Identifies needed capabilities to accomplish mission or project objectives, and the activities required to deliver the needed capabilities
- Identifies where capabilities or activities are insufficient or missing
- Identifies solution(s) to insufficient or missing capabilities

Fully Integrated

B. Fully integrated

- Uses consensus building to reach decisions (the process is as important as the product)
- Facilitates the participation of problem-owners, solution-provider(s), customers, and stakeholders (which may include internal [safety, maintenance, etc.] and external groups [regulators, State/tribal oversight, citizen groups, NAS, etc]).

Comprehensive



C. Comprehensive

- Addresses the program's or project's life-cycle (near-, intermediate-, and long-term needs and objectives)
- Considers the full range of potential solutions, from basic science to applied research, technology development, demonstration, deployment, and technical assistance).

Credible Decision Process

D. Credible and defensible decision process

- Identifies the capabilities needed, the alternatives considered, and the criteria and data used to arrive at decisions
- Documents the reasons for the decisions
- The quality of the process determines the value of the product.

When Should Roadmapping be Used?

Roadmapping is a powerful, high-end planning tool. In general, its use is most valuable to programs or projects when any of the following is present:

1. High potential for mission failure
2. Significant consequences if failure occurs
3. High dollar costs, high worker exposure, or high environmental impact
4. Multiple, diverse efforts working on a common problem
5. Significant political or senior management visibility.

Several conditions lend themselves to successful roadmap development, including:

- A strategy exists for completing the mission of the cleanup program or project, or science and technology roadmapping will be conducted as part of establishing the strategy.
- The program or project has identified significant technical risks in the baseline or significant technical opportunities to improve the baseline.
- The cleanup and the R&D organizations are willing to jointly sponsor (fund) needed R&D activities, or related R&D activities are already being jointly sponsored (funded).

SECTION II - HOW TO ROADMAP (Overview)

The Roadmapping Process and Products

The roadmapping process has four phases: roadmap initiation, technical needs assessment, technical response development, and roadmap implementation. Each phase is described briefly in this section and in more detail, including examples, in Appendix A. Figure 1 shows the primary steps and products of each phase.

A requisite for science and technology roadmapping is sound program and project planning. Typically, science and technology roadmapping is conducted concurrent with general program and project planning prior to pre-conceptual design. As alternative approaches are considered, the science and technology activities needed to support each promising approach are identified. This document does not address general program and project planning, and is written to support science and technology roadmapping either during program/project scoping or after an initial approach has been selected. In both cases, roadmapping helps round out the baseline by identifying the complement of science and technology activities.

Phase I: Roadmap Initiation

The first phase, roadmap initiation, is preparation for the actual roadmapping process. These pre-roadmapping steps are critical to roadmapping success, as they ensure the effort is sufficiently defined and supported. These steps include agreement on the roadmap's scope, leadership, participants, and deliverables.

Phase II: Technical Needs Assessment

Technical needs assessment is the most important phase of the roadmapping effort. This phase includes a structured approach to identification of technical issues, assessment of current capabilities versus those issues, and identification of capability gaps and associated R&D goals. This phase is complete when a consensus is developed and documented on the technical needs and gaps and the direction for R&D.

Phase III: Technical Response Development

In Phase II, the cleanup problem-driven needs for science and technology development were established. In Phase III, the responses to those needs are mapped out. At this point, the focus shifts from the cleanup community and the capabilities needed, to the R&D community and the technologies to provide those capabilities.

Phase IV: Roadmap Implementation

In Phase IV, the roadmap report is reviewed, released, and implemented. This phase begins with management briefings on the roadmap findings, independent technical reviews, and report finalization. After release of the roadmap report, implementation plans are developed, R&D budgets allocated, and R&D work plans executed. Implementation progress is tracked and the roadmap report revised and updated as needed.

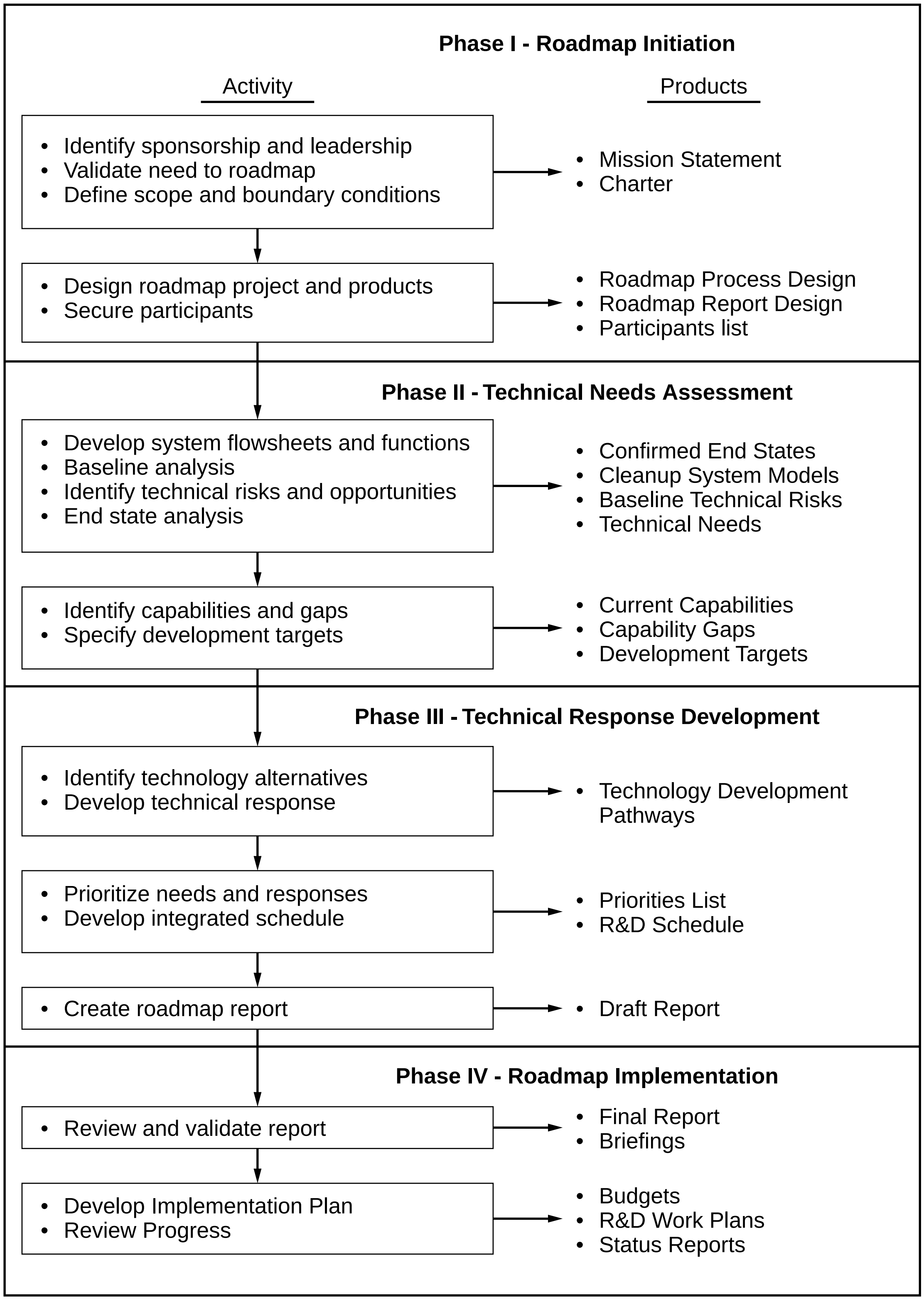


Figure 1. Roadmapping process and products

Roadmap Examples and Checklist

This section provides examples of project- and program-level roadmaps. A generic checklist also is provided in Table 2.

Project-Level Roadmapping Example

Throughout Appendix A, examples from the project-level SRS HLW salt processing roadmaps are used to illustrate the text (see Figures A-4, A-5, A-8, and A-9 and Tables A-1, and A-2). This roadmapping effort was initiated to develop alternatives for processing of the salts after the baseline technology, In-Tank Precipitation (ITP), as originally planned, was deemed unworkable due to problems encountered soon after initiating operation.

The "ITP alternatives" activity was a combination project replanning and science and technology roadmapping effort. Approximately 140 alternatives were screened, 18 alternatives assessed, and 4 final alternatives subjected to detailed evaluation. Two of the alternatives (a primary and a backup) were recommended by the planning team for parallel development Both of the alternatives were roadmapped to identify science and technology activities necessary to investigate technical viability and identify design parameters. The results from these activities will support final process selection.

The project planning documents and roadmaps were reviewed during development by an independent review team. After completion, DOE requested additional review by the National Academy of Science. Because the project has high technical risk and high political visibility, the R&D activities are now being implemented for a second backup process as well as the two processes originally recommended.

Program-Level Roadmapping Example

The only completed EM program-level roadmap at this time is the Hanford GW/VZ roadmap (Figure 10 was drawn from that roadmap). However, due to the large amount of detailed documentation in the roadmap, it cannot be adequately represented in this report.

Since no simple example of an EM program-level roadmap is available, an abbreviated hypothetical example has been created for this document. Figure 2 shows how the process is applied for a program-level subsurface cleanup roadmap. The first part of the example focuses on one area of technical need and shows the identification and presentation of phased development objectives followed by the identification and presentation of technical response paths for the need.

The second part of the example in Figure 2 shows how the same process is applied across all the needs. A full set of technical responses is developed and the results are displayed in a number of maturity and ***development path charts***, along with back-up tables describing the needs and response activities in detail. Figure 3 shows how the results of a program-level roadmap would be graphically presented on ***capability maturity charts*** and technology development path charts.

Program-Level Roadmap

Need – General: Improve non-intrusive subsurface characterization. Specific: Improve 3-dimensional imaging with a performance objective of 1 ft resolution at depth.

Targets – Development targets for non-intrusive 3-D subsurface feature detection at 1 ft resolution are set at a 50-ft depth today, 100 ft by 2005, 500 ft by 2010, and 1,000 ft by 2020.

Gap Analysis – Current capabilities include ground-penetrating radar operating at the required resolution to 50ñ60 foot depths, and 3-D seismic imaging operating to depths of thousands of feet, but only at 10-ft vertical and 50ñ100 ft horizontal resolution. Current development includes extension of radar to 100-ft levels. The targets and current capabilities are presented in a capability maturity chart, as shown in Figure A.

Deployment Dates	2000	2005	2010	2015	2020
3-D Imaging (1-ft resolution)	50 ft	100 ft	500 ft	500 ft	1,000 ft

Solutions Exist   Solutions Being Pursued   No Known Solution

Figure 2A – Hypothetical example of capability maturity chart

Technical Responses – The roadmapping team determines that two separate technical response paths are to be developed, one for the near-term target, and one for the reach out [long-term] target. The technical responses are presented in a technology development path chart, as shown in Figure B.

- The first path includes development, demonstration, and deployment of a relatively low-risk extension/refinement of the ground-penetrating radar system capability to 100 ft depths, with development completed in 2003 and demonstration in 2004. This addresses the 2005 target.
- The second path addresses the higher-risk 500- and 1,000-ft depth targets, initially employing three alternative technology approaches – one each for breakthroughs in deep ground-penetrating radar and high-resolution 3-D seismic imaging, and a third to develop a new (unknown) alternative. The three paths would each include research and initial development leading to an evaluation in 2006. Only the most promising alternative will be pursued after that time. Final development will be completed by 2008, with demonstration and deployment of a 1,000+ ft capability by 2010. This addresses both the 2010 targets.

Figure 2B – Example of technology development paths chart

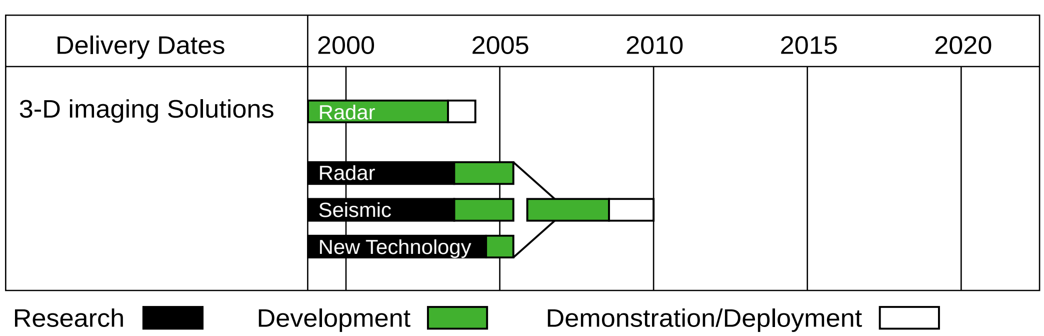


Figure 2. Example of program-level roadmap. (Note: This example is provided for illustration purposes only. It is not technically accurate, and does not reflect any actual EM planning activity.)

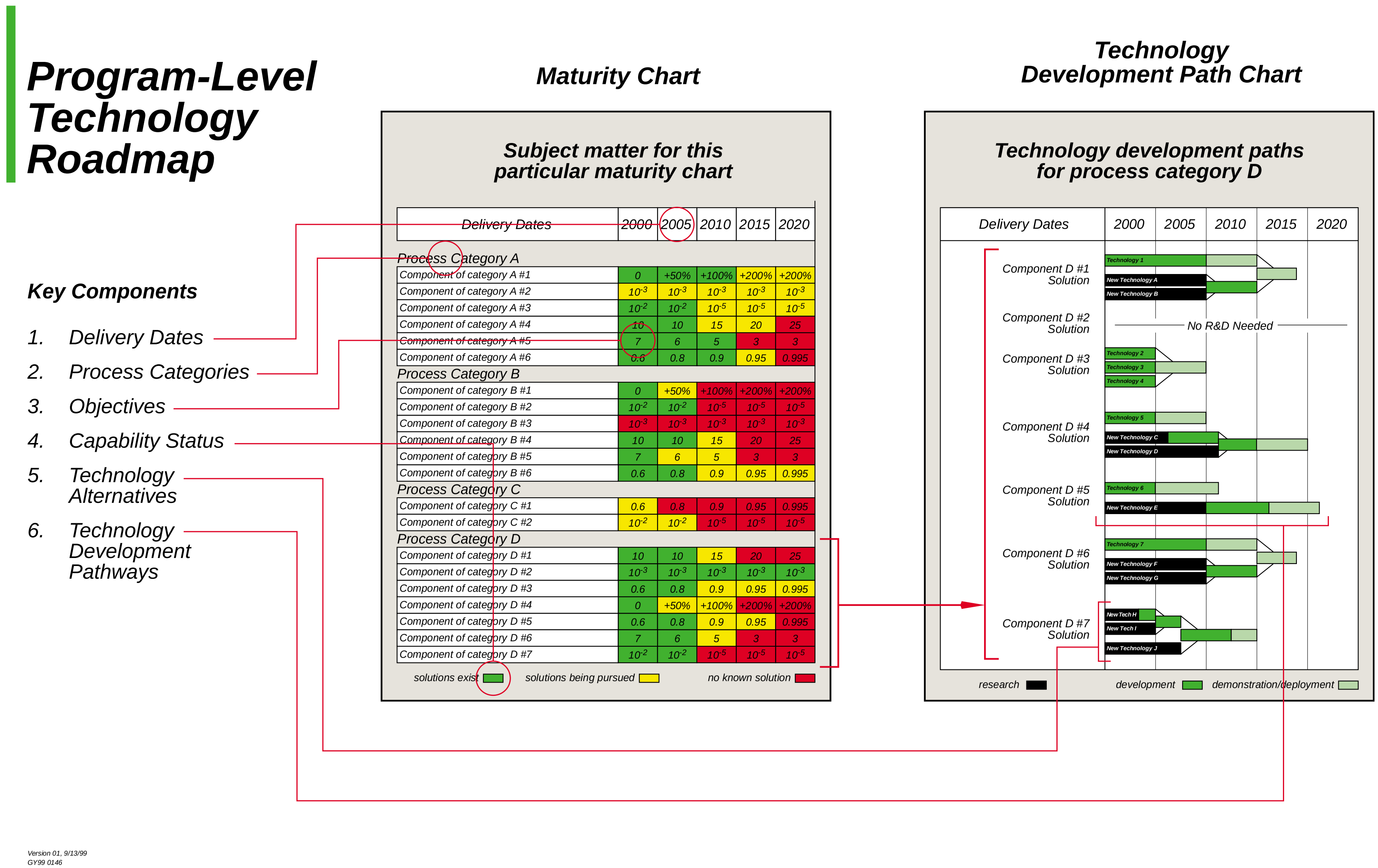


Figure 3. Relationship between maturity charts and development path charts for a program-level roadmap.

Table 2. Generic checklist

Phase I: Roadmap Initiation

- ❑ Roadmap project lead identified
- ❑ Mission and charter approved
- ❑ Organizational structure and roles and responsibilities established
- ❑ Communications strategy established
- ❑ Preliminary schedule established
- ❑ Project plan approved
- ❑ Budget secured
- ❑ Work group leads secured and core team finalized
- ❑ Process design review completed
- ❑ Initial core team meeting held
- ❑ Schedule finalized
- ❑ Roadmap participants finalized
- ❑ Roadmap meeting locations secured and logistics mapped

Phase II: Technical Needs Assessment

- ❑ Information packets set to participants prior to first joint meeting
- ❑ Orientation session completed
- ❑ System flowsheets and unit function descriptions completed
- ❑ Risks/opportunities identified and documented
- ❑ Relevant technologies identified
- ❑ Work group sessions scheduled and logistics addressed
- ❑ Meeting results documented
- ❑ Science and technology evaluated by work groups and maturity identified
- ❑ Gap analyses completed
- ❑ Development targets for gaps completed

Phase III: Technical Response Development

- ❑ Technology alternatives for targets identified
- ❑ Technical responses completed
- ❑ Work group reports completed and distributed to participants prior to second joint meeting
- ❑ Work group results presented and discussed
- ❑ Needs and responses prioritized
- ❑ Integrated schedule completed
- ❑ Agreement on major findings reached
- ❑ Format of report finalized
- ❑ Writing assignments made
- ❑ Meeting results documented
- ❑ Writing assignments completed
- ❑ Report graphics completed
- ❑ Final editing completed
- ❑ Draft roadmap report issued

Phase IV: Roadmap Implementation

- ❑ Roadmap draft internal & external reviews completed
- ❑ Management briefed on project and major findings
- ❑ Comment resolution completed
- ❑ Final roadmap report completed and approved
- ❑ Report/findings/decisions published and distributed
- ❑ Implementation plan developed, approved, and funded
- ❑ Periodic review of progress
- ❑ Update report/plans as appropriate

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The references have been divided into three categories to enable the reader to more quickly locate and compare similar documents. The categories are: Roadmap Process Documents, Roadmap Reports, and EM Source Documents

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Glossary

Alternate technology – An alternate technology is one of several technologies that exist or can be developed within the timeframe required to meet one or more targets for a science and technology roadmap.

Boundary Conditions – The range of study that is determined to fall within the roadmap project scope along with the interfaces that must be examined or analyzed by a roadmap. Conversely, defining the boundaries determines what is outside the area of interest.

Capability Maturity Chart – A chart or matrix used in the semiconductor industry's technology roadmaps to graphically depict development targets and related capability status (e.g., solutions exist, under development, none known).

Champion, Sponsor – The person who clearly owns the end state or roadmap product, and who provides high-level coordination for all activities requiring senior-level concurrence, direction, and approval. The sponsor may also have a responsibility for program management and implementation of the final roadmap plan.

Critical/Emerging Technology – A new technology promising broad application, but not developed enough to clearly identify all specific uses and benefits. Investments in emerging technologies tend to focus on core capabilities rather than specific applications. Examples in DOE include robotics and computer simulations. An emerging technology roadmap plans development of core capabilities for an emerging technology and is not driven by specific product requirements.

Decision Point(s) – Critical milestones where project-level decision-making is timed when both enough and the right information is available to make technology decisions.

Development Path Chart – A chart or graphical representation used in the semiconductor industry's technology roadmaps to depict the linkage and timing of research and development activities related to specific development targets. They are used in conjunction with capability maturity charts to show the path forward for solution development.

Development Target – A date for obtaining a specific level of technical capability associated with a particular cleanup function. This may be in the form of a specific performance requirement or a more general metric.

Disruptive Technology – A technology both significantly superior to and different from current technologies such that it not only changes how a related technology problem is solved, but also changes customer expectations and requirements. Examples include the telephone, the automobile, and the Internet.

Environmental Management (EM) Program –An office within the U.S. Department of Energy that was created in 1989 to oversee the Department's waste management and environmental cleanup efforts. Originally called the Office of Environmental Restoration and Waste Management, it was renamed in 1993.

EM Science and Technology Roadmapping –A planning process to help identify technical capabilities needed for both project- and program-level efforts, map them into technology alternatives, and develop project plans to ensure that the required technologies will be available when needed.

Gap Analysis – A step in the roadmapping process that compares needed functionality to existing capability and highlights the difference or "gap" between them.

Gate Model – A linear maturation model where core technical criteria are applied to assess the maturity of research and development projects. As used in DOE's Office of Science and Technology (OST), a management system of six screening reviews to track R&D project advancement through the stages of basic research, applied research, exploratory development, advanced development, engineering development, demonstration, and deployment.

Industry Technology Roadmap – A technology roadmap developed collaboratively to address specific needs of multiple companies, either as a consortium or as an entire industry.

Issues-oriented Roadmap – A program planning tool used to identify issues and their consequences. Used by EM ca. 1991–1992 to assess regulatory compliance.

Metrics – A variable that can be quantified and measured and may be used to define a technology development target.

Milestone – A defined date on a project timeline associated with formal completion of an activity or project phase.

Mission/Charter – A clear statement of the task to be performed by a project, and the authorities, constraints, and environment that affects its execution.

Program Level Science and Technology Roadmap – An EM roadmap embracing the technical needs of a program; a set of related projects; or a common, broad problem area. Program-level roadmaps usually address long-term capability improvements.

Project Level Science and Technology Roadmap – An EM roadmap embracing the technical needs of a specific project. Project-level roadmaps usually address specific technical uncertainties or unproven assumptions critical to successful project execution.

Scenario-Based Planning – A planning methodology that explicitly addresses uncertainty about the future by allowing planners to identify several alternate future states or scenarios so that prerequisites for or consequences of alternatives can be considered. In science and technology roadmapping, scenario-based planning provides a mechanism to deal with uncertainty in either product needs or technological developments.

System Flowsheet – A graphical representation of a cleanup procedure or physical process indicating primary ***system functions*** or physical components and their process-interface relationships.

System Function – A discrete step or unit operation in a cleanup process, usually associated with waste/material examination, transformation, separation, or repackaging.

Target – An objective of achievement for products or nodes that are charted to reach or achieve by a near- and long-term year objective proposed as a reasonable stretch goal.

Technology – The use of science- and engineering-based knowledge to meet a need.

Technology Driver – Factors that determine which technology alternatives will be pursued, including cost, schedule, public or worker risk, waste minimization, environmental impact, regulations, or political factors.

Technology Insertion Point – A predefined point in a project schedule when new technologies will be considered for inclusion in the project baseline. Insertion points are scheduled to minimize disruption to project designs while maximizing the potential benefit of applying new technologies.

Technology Planning – The process for identifying, selecting, and investing in the technologies that are required to support those product and service requirements identified in a company's strategic plan. Technology roadmapping is one form of technology planning.

Verification/Validation – The full scope of activities that take place to ensure that individual components or systems meet established performance requirements and that products or results meet customer expectations and performance metrics based upon validation tests prior to deployment.

APPENDIX A - HOW TO ROADMAP
(Detailed Discussion)

The Roadmapping Process and Products

The roadmapping process has four phases: roadmap initiation, technical needs assessment, technical response development, and roadmap implementation. Each phase is described in this section and illustrated with examples from EM science and technology roadmaps. Figure A-1 shows the primary steps and products of each phase.

A requisite for science and technology roadmapping is sound program and project planning. Typically, science and technology roadmapping is conducted concurrent with general program and project planning prior to pre-conceptual design. As alternative approaches are considered, the science and technology activities needed to support each promising approach are identified. This document does not address general program and project planning, and is written to support science and technology roadmapping either during program/project scoping or after an initial approach has been selected. In both cases, roadmapping helps round out the baseline by identifying the complement of science and technology activities.

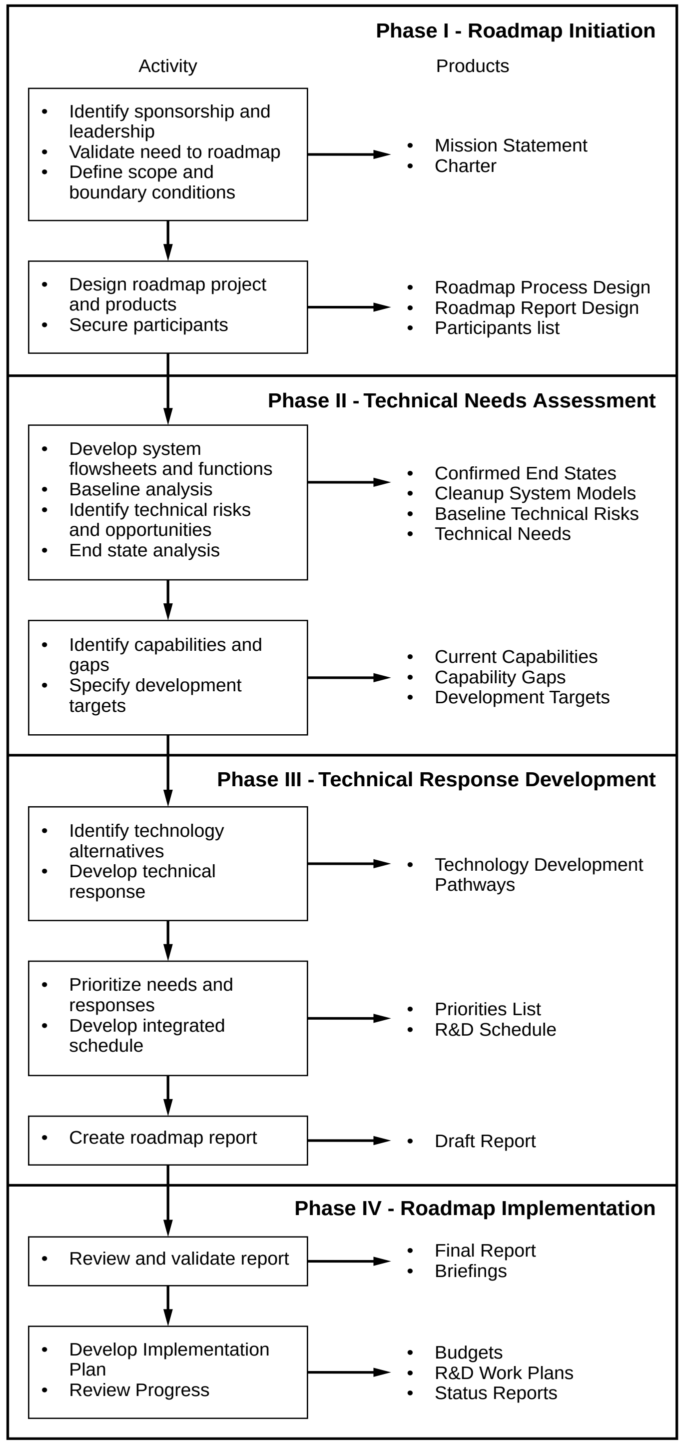

Figure A-1. Roadmapping process and products

Phase I: Roadmap Initiation

The first phase, roadmap initiation, is preparation for the actual roadmapping process. These pre-roadmapping steps are critical to roadmapping success, as they ensure the effort is sufficiently defined and supported. These steps include agreement on the roadmap's scope, leadership, participants, and deliverables.

Obtain sponsorship and leadership

Usually the roadmap ***sponsor*** is the "problem holder," the person responsible for completion of the associated mission work scope; the program or project manager, with support from a DOE champion in the field office. The program/project manager endorses the decision to roadmap, approves the roadmap's scope, assigns the roadmap lead, and secures the necessary funding. At the project level, the decision to roadmap should be part of the project manager's initial scoping effort. Technical complexity should be assessed in the same manner that other major project aspects are scoped (See Figure A-2).

Project Scoping Checklist

ES&H Requirements
➡ High (nuclear facility)
⟶ Develop full Safety Analysis Report

Technical Complexity
➡ High (major technical issues)
⟶ Develop science and technology roadmap

NEPA Requirements
➡ Moderate (environmental consequences)
⟶ Develop Environmental Assessment

Procurement
➡ Moderate (construction related subcontracting)

Figure A-2. The need for roadmapping is typically determined by the project manager during initial project scoping.

Most roadmaps are initiated by the sponsor. However, a program-level roadmap may be initiated when several project managers or technology providers identify a common cleanup problem for which no single formal organization exists. In this case, a sponsor must be identified and brought on board before proceeding further. For complex-wide efforts, a Headquarters sponsor is preferred. If a single sponsor can't be identified, an existing representative committee can sponsor a roadmap.

Because of the time and effort involved in roadmapping, there must be committed leadership. The roadmap project lead must be visionary and should come from the group that will benefit from the roadmap. The roadmap lead should have solid project management and team-building skills, good technical knowledge of the supported mission, and experience in roadmapping. If the lead lacks roadmapping experience, an advisor or consultant can be employed. The roadmapping advisor need not be a technical expert or even particularly knowledgeable in the subject domain of the roadmap. In fact, such expertise can be a detriment, allowing the advisor to become too involved in the technical subject matter. The roadmap leader should communicate frequently with the sponsor throughout the project.

Validate the need to roadmap

After a sponsor is determined and a leader appointed, the next step is to validate the need to roadmap. Roadmapping should be used for high risk, high visibility, high cost, or highly complex projects or programs. Whether to roadmap a particular project or program is subjective. However, if a project or program meets one or more of the following criteria, it is a good candidate for roadmapping:

- The project has a high technical risk rating (e.g., it has an IPABS stream, TSD, or ***milestone*** technical risk of 4 or 5 or a "red light" on the associated disposition map), or is on the site closure critical path and has moderate to high technical risk.
- The project is in the conceptual design or execution phases (pursuant to DOE Order 430.1A), but the baseline includes unproven technologies.

- The project is a one-of-a-kind effort with significant consequences for cost or schedule slippage.
- Multiple, diverse efforts are working on a common problem.
- The program is long-term and has high worker exposure, life-cycle dollar, or environmental costs.
- The project or program has high political or management visibility.

Define the roadmap scope and boundaries

Before the actual roadmapping effort begins, the scope and boundaries must be specified and agreed to by the sponsor and formalized in a mission statement and ***charter***, also approved by the sponsor. A clear definition of the scope and boundaries communicates the roadmap's purpose and limits to sponsors, participants, observers, and reviewers.

For project-level roadmaps, the scope usually includes all the technical capability needs of and related R&D efforts for the cleanup project. The timeframe for R&D results is driven by schedule requirements of the cleanup project.

Scope and ***boundary conditions*** for program-level roadmaps usually require more definition. The scope may encompass all aspects of a cleanup problem area, or only some functions. For example, the scope of the Complex-Wide Vadose Zone (CWVZ) roadmap addresses characterization, assessment, and monitoring, but excludes remediation. The scope may address the full system, or only selected parts. The Hanford GW/VZ roadmap addresses the full subsurface system, from contaminant sources to the Columbia River, while the CWVZ roadmap focuses only on the subsurface down to the groundwater. The scope may take in activities that span multiple organizations, or only one organization. The CWVZ roadmap addresses monitoring for both cleanup and stewardship – a common technical issue for two very different mission phases. Finally, the timeframe of the roadmap should be specified. Program-level roadmaps usually have timeframes of 10 to 30 years.

Design the roadmapping project and product

Once the scope and boundaries are defined, the roadmap project and product can be designed. The design typically includes the roadmapping process, organizational structure, communications, budget, schedule, and products. However, each roadmap is unique, and each must be tailored to the specific circumstances. This document is intended only to provide guidance on essential features or typical processes and products.

All roadmapping efforts involve collaboration and consensus building between personnel representing different perspectives on the problem. Project-level roadmaps typically involve fewer people, but more meetings, while program-level roadmaps involve more people, with few full-team meetings and most of the work done by committees or work groups. If work groups are used, full team workshops should be sequenced and scheduled for all work groups to come together and share results, gather consensus, and focus direction for resolving key issues. The process shown in Figure A-3 can be used as a guide but should be modified as needed for the number of meetings and working sessions.

To be effective contributors throughout the science and technology roadmapping process, participants must have a basic understanding of how the process is applied (or is being customized), for a particular project-level or program-level roadmap. This information should be provided during the first workshop. If this is the first roadmap for

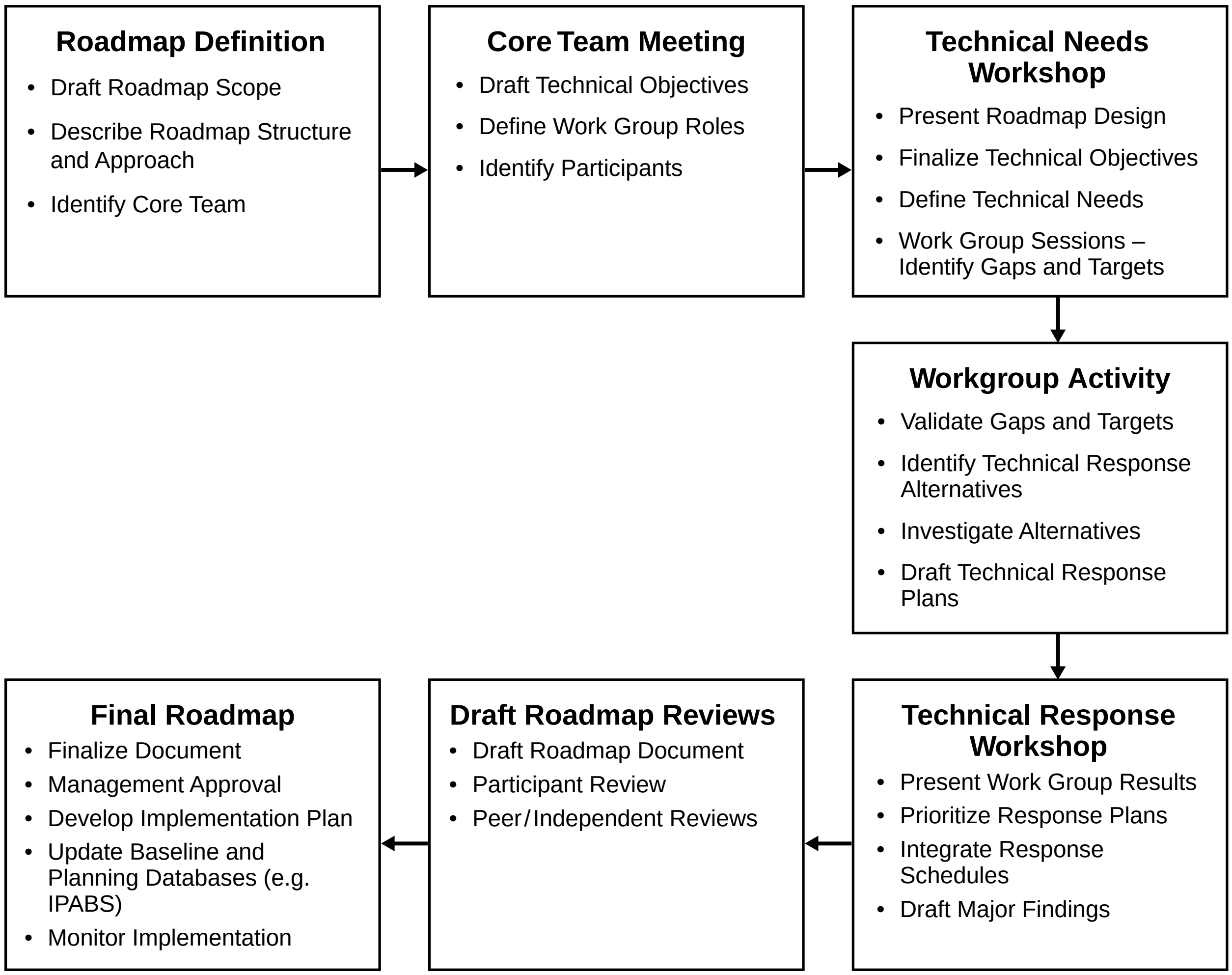

Figure A-3. Generic roadmapping activity sequence

many of the participants, the overview should be expanded or a separate orientation or training session on roadmapping added. Without a basic understanding, consistency in the documentation framework, the level of detailed analyses completed within each step of the process, and the coordination of information exchange among work groups and participants will suffer.

Along with the work groups, larger roadmapping efforts usually also have a core team composed of the work group leads, a full-time support team, an independent review team, and other structure. The core team organizes the work groups and ensures their products are consistent and integrated. The support team manages logistics, communications, and report production. The review team provides independent technical reviews of intermediate products to confirm they are complete and of sufficient quality to support the next steps in the process.

The basic features of the final report should be designed at this stage to ensure necessary information is developed during the roadmapping process. The design should include the general format and primary layout of the graphics and tables. Two considerations of design are the roadmap's primary purpose and the principal audience. The purpose of a roadmap varies from marketing tools to policy statements to budgeting tools to working plans. Program-level roadmaps often are used to develop consensus on general R&D direction and priorities, while project-level roadmaps tend more toward working plans for the sequence of R&D activities needed to make informed project decisions. The principal audience may be Congress, DOE Headquarters, local managers, science and technology users, developers, or other stakeholders.

Although up-front project and product planning are important, a key lesson learned is the need to be flexible during execution. After each major meeting, the leadership or core team should assess the need for course corrections. A second lesson learned is to resist the tendency to over-analyze. A roadmap is a strategic plan, and "roughly right" is usually close enough, especially at the program level. Additional analysis, if necessary, can take place during implementation.

Identify and secure participants

Roadmapping is a multidisciplinary, consensus-building process. The final product is owned by the group of participant-experts that developed it, and its success is shaped by the group's commitment to actively participate in the process, and by the continuous involvement and interaction among the work groups, the steering committees, and management oversight.

Building the right roadmapping team involves identifying the experts in select fields, and screening, selecting, and/or recruiting the right people with the right knowledge and skills to match the mission and the requirements. Screening criteria will ensure the right experience and skill mix is represented. The screening criteria should be applied to the selection of participants as well as the selection of work group leads and other key positions.

A roadmap team may involve from two-dozen to more than five-dozen participants, depending on the breadth and complexity of the scope. The participants should be respected authorities or experts in their areas. Preference should be given to people with broad knowledge and experience and the reputation for identifying what is needed for the common good.

Participants should be selected based not only on their specific expertise and credentials but also on their ability to contribute to all phases of the roadmapping process. Participants will be asked to manage information in real time, focus on the overall mission ***targets*** as well as critical knowledge and technology gaps, anticipate the future, and reach a shared vision of the needed path forward. Because of the need to actively contribute during work sessions, a participant's ability to perform as a member of an interdisciplinary team is just as important as their ability to apply independent skills.

Participants should be drawn from several areas to ensure a multidisciplinary team. For a project-level roadmap, participants may include project managers, project technical experts, plant engineers, scientists, technology development engineers, and representatives from disciplines such as safety and maintenance. At the program level, participants from other sites, national laboratories, government agencies, universities, and industry should also be considered.

Depending on the project or program's public visibility, representatives of regulatory, oversight, and other stakeholder bodies could also be involved. Experience has shown that involving regulators, Indian Tribes, and stakeholders early in planning efforts can add value and diversity to the range of alternatives considered.

Phase II: Technical Needs Assessment

Technical needs assessment is the most important phase of the roadmapping effort. This phase includes a structured approach to identification of technical issues, assessment of current capabilities versus those issues, and identification of capability gaps and associated R&D goals.

Once a consensus is developed and documented on the technical needs and gaps and the direction for R&D, the roadmapping effort can be considered a success. In fact, some roadmapping efforts end at the completion of this phase, delegating the identification of promising technologies and the development of technical responses to the research organization.

Develop system flowsheets and specify system functions

The major unit operations or functions of the related cleanup system are documented to form the basis for a systematic needs assessment. The documentation should include a ***system flowsheet***, a graphical representation of the system, along with a table that describes the function and the performance requirements[5] for each unit operation in the flowsheet. If more than one cleanup approach is under consideration, a flowsheet for each approach should be developed. Tiered flowsheets may be used to show important details.

Figures A-4 and A-5 are examples of tiered flowsheets. The high-level waste disposition map shown in Figure A-4 includes an area of high technical risk: the "Salt Processing (Decontamination)" function that appears near the middle of the figure. Figure A-5 is the system flowsheet for one of the three salt-processing alternative approaches that have been roadmapped.

At the program level, generic system flowsheets should be developed to represent the multiple planned and potential projects. The generic flowsheets should cover what is planned on near-term projects as well as what is projected (such as potential future systems that would be more effective but may require significant successful R&D over several years to become a reality). Although performance requirements will not be as precise for generic systems, the flowsheets should reflect desired efficiency levels.

Identify and specify areas of technical risk or opportunity

In this step, each function and each interface between functions on each flowsheet is assessed against its performance requirements to determine the associated level of technical uncertainty. Functions expected to use off-the-shelf equipment that has been employed many times before for the same purpose and at the same scale have minimal technical uncertainty. First-of-a-kind applications likely to use technologies that are unproven or have yet to be identified have the highest technical uncertainty.

For project-level roadmapping, technical uncertainties and unproven assumptions are identified, along with the related consequences to the system. The combination of degree of uncertainty and severity of consequence results in a relative technical risk ranking for each item. If the uncertainty is only applicable to a part of a function, a subsystem flowsheet for the function may be needed to clearly identify the uncertainty and system consequence. This cycle of identification and specification continues until the roadmapping team believes they have

[5] These are equivalent to initial, high level Functional and Operational Requirements (F&ORs).

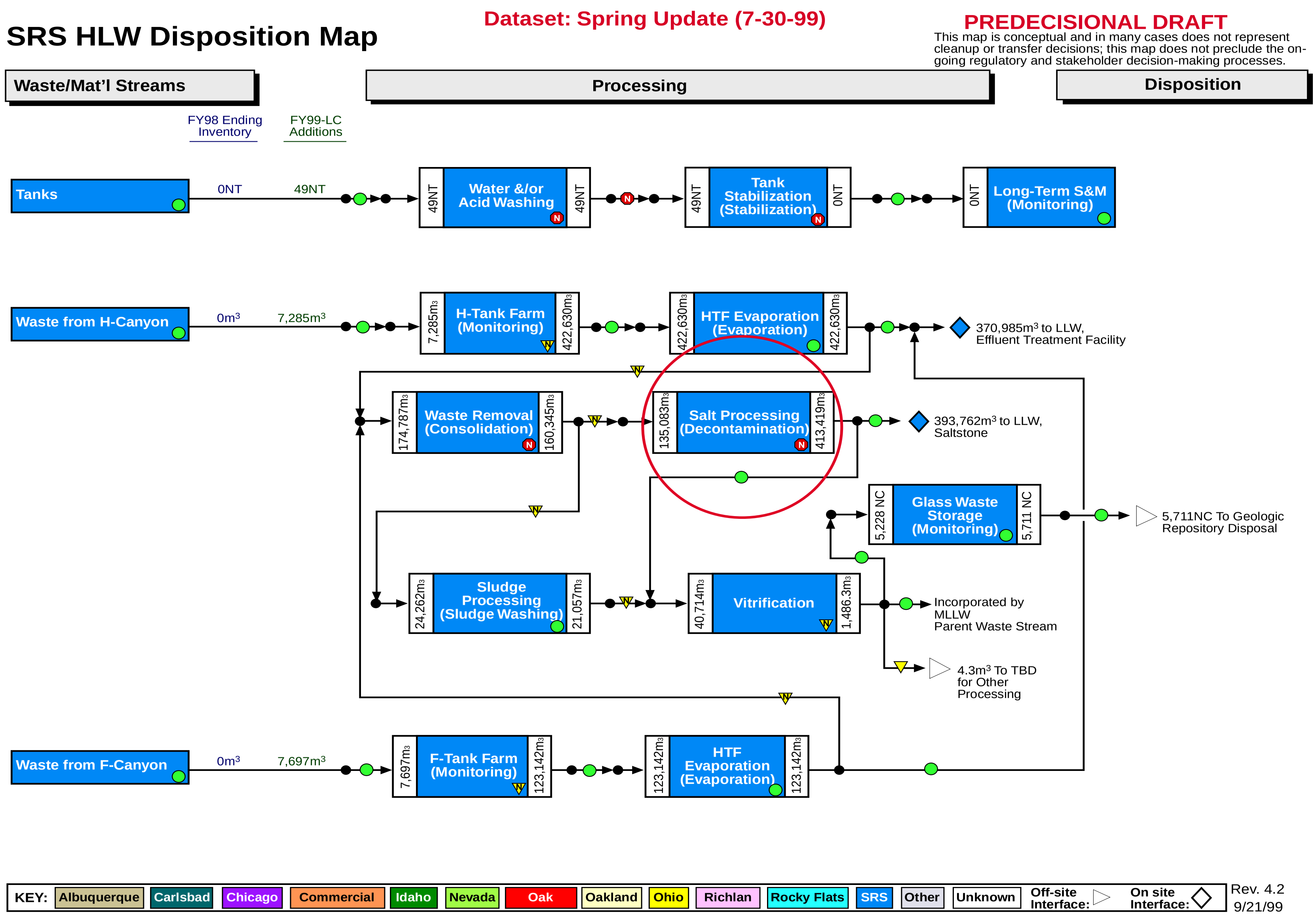

Figure A-4. Disposition map from Savannah River Site (SRS) High-Level Waste (HLW) Roadmap. Risk levels for functions and interfaces are indicated by green "go", yellow "caution" and red "stop" symbols.

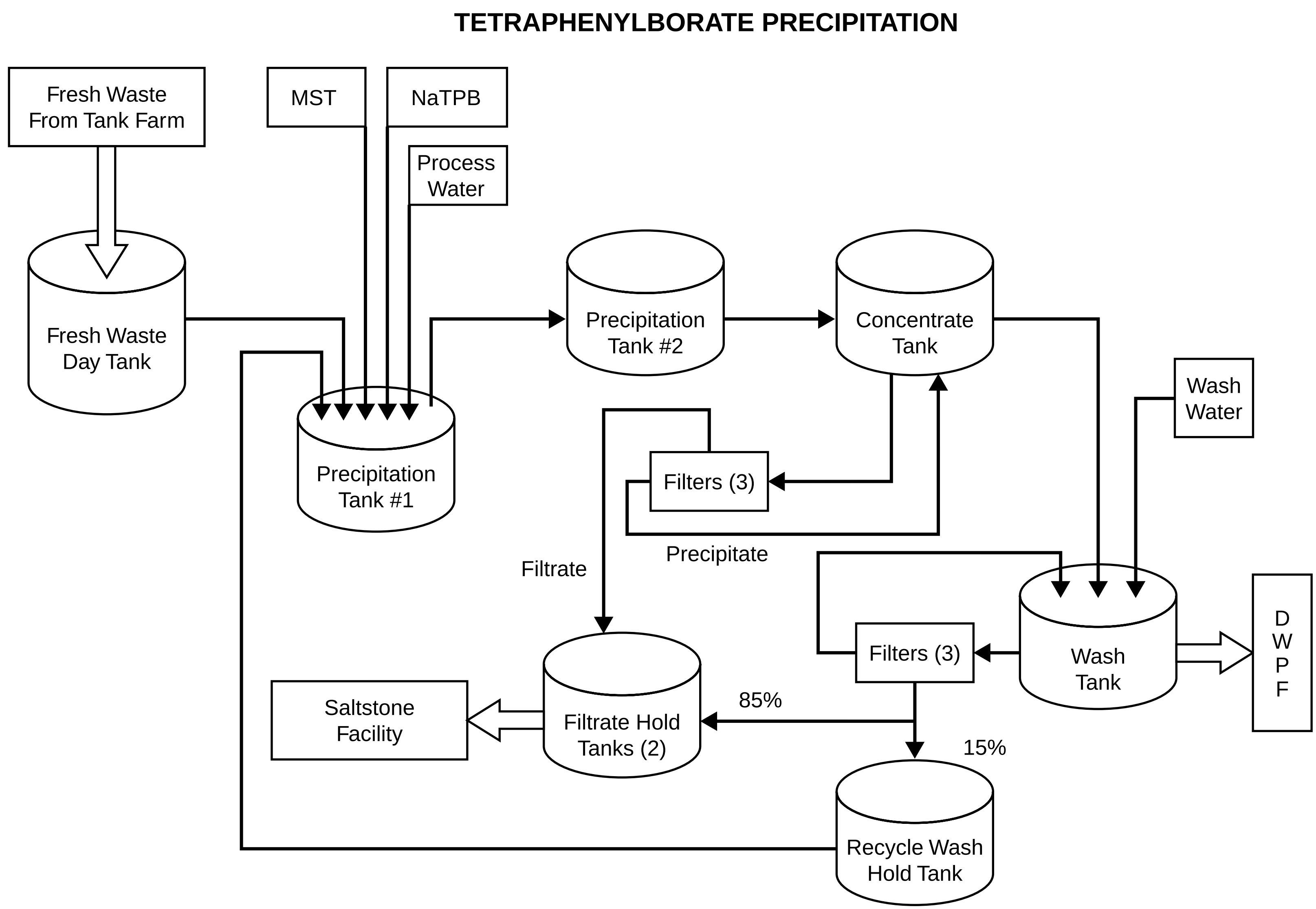

Figure A-5. Sample project level system flowsheet. This flowsheet is tiered from the salt-processing function of the SRS HLW disposition map shown in Figure A-4.

identified all the significant technical risks of the project. The uncertainties and consequences are documented in tables and grouped by relative risk (usually high/ medium/low). Relative risk values may also be emphasized on the flowsheets via symbols or colors, as was done in Figure A-4. The result of this step will be a roughly ranked list of uncertainties/assumptions to be investigated. Table A-1 shows part of a table documenting uncertainties for one of the SRS HLW salt processing alternatives.

At the program level, potential future systems will typically have very high uncertainties, which is balanced by the opportunities those future systems represent for more efficient mission achievement. For this reason, program-level roadmapping focuses on technical opportunities instead of technical risk. Thus, at the program level, functions of generic systems are considered, and the benefits of major improvements in the performance of these functions over the longer term are assessed. A general strategy for these improvements is developed, including the desired end state systems. Improvement goals are specified for each function in the desired end state systems.

Identify technical capabilities and identify gaps

Next, each significant project risk or program improvement goal is assessed for technical solutions that are either available or currently under development. The specific technologies and their maturity are added to the developing information tables, along with the remaining gap between current technical capability and functional need.

This step involves brainstorming to identify potential alternate solutions, followed by screening and more in-depth research on the most viable solutions. The goal is to use a graded approach to ensure nothing promising is overlooked and the real gap between capability and need is clearly defined.

Specify development targets for each gap

At this point, ***development targets*** are established for each identified capability gap. At the project level, the targets should be very specific and tied to the project schedule. They should specify proof-of-concept, scaling demonstration, and other technology maturity points that coincide with the timely engineering of the cleanup system. R&D target scheduling is intended to mitigate technical risk by achieving measured reductions in the technical uncertainty before commitment of significant resources for facility design and construction. Thus, all proof-of-concept targets should be scheduled for completion before the end of pre-conceptual design, and all scaling demonstrations and similar information needed for facility sizing and cost estimating should be scheduled for completion before the end of conceptual design.

At the program level, development targets are set and scheduled to achieve the greatest benefit for multiple projects. First, development phases are identified that represent measured steps toward the previously defined end state. The phases are scheduled for completion in time to benefit key projects or groups of projects, as illustrated in Figure A-6. Next, development targets are identified for each capability gap within each phase. The targets are often described as percent performance improvement versus current state of the practice. Nearer-term targets will typically be minor performance improvements (10–30%) that can to be achieved through incremental improvement of current technologies. Longer-

Table A-1. Sample work scope matrix from the SRS HLW Roadmap for the crystaline silicotitanate

Item No.	Item	Considerations
	Process Chemistry	
1	Alpha Removal Kinetics and Equilibrium	The addition of Monosodium Titanate (MST) has been proposed to adsorb the soluble U, Pu, and Sr contained in the waste stream. The rate and equilibrium loading of these components as a function of temperature, ionic strength and mixing is required to support the batch reactor design. Initial data from batch reactor data indicates the MST kinetics require more than the 24 hrs assumed in pre-conceptual design resulting in larger reactor batch volumes. Studies will be conducted to determine if the MST strike could be completed in the existing SRS waste tanks. Alternatives to MST will be investigated.
2	Cesium Removal Kinetics and Equilibrium	The ability of CST to remove Cs from aqueous waste solutions needs to be investigated as a function of temperature and waste composition. Potassium, strontium, nitrate, and hydroxide are known to impact the equilibrium loading of Cs on the CST. Mass transfer coefficients as a function of column geometry and velocity vs. difficivity must also be determined to ensure proper ion exchange column sizing. The ability of CST to sorb Sr, Pu and U must be determined to avoid potential criticality issues. De-sorption of the Cs due to normal and abnormal operations such as temperature swings must be determined. Thermal stability of CST must be determined.
3	Radioactive Bench Scale Ion Exchange Column Studies	Radioactive bench scale column tests must be conducted to determine the radiolytic generation rate of hydrogen and other gases. These gases represent potential safety and column operational issues.
4	Solubility Data	Solubility of various salts must be determined to define the lower bounds of operating temperature and minimum tank farm dilution requirements.
5	Physical Property Data	General physical property data such as density, viscosity, yield stress and consistency of slurries, as a function of state variables such as temperature is required to support the design effort. Settling velocity and re-suspension requirements must be determined.

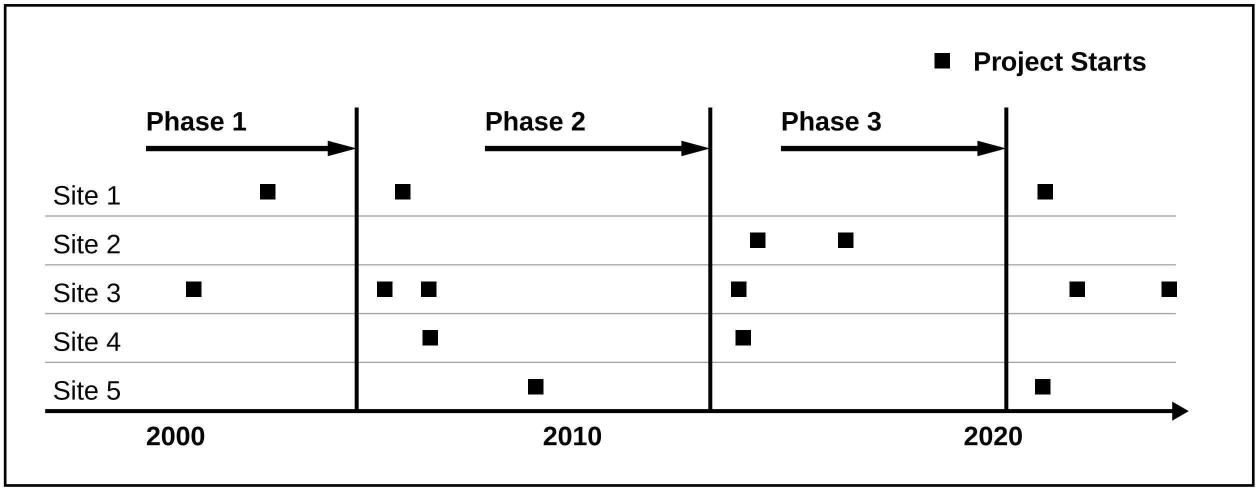

Figure A-6. Example showing how program-level roadmap development phases are scheduled to support start-up of related projects

term targets are often major performance improvements (100–1000%) that require new technologies. Long-term targets are designed to challenge the R&D community to pursue and achieve major breakthroughs for use on future cleanup projects, and should only be developed if significant/key projects are not scheduled to start for another 10 years or more.

The end of Phase II is a good time to stop for a mid-roadmap review. The review should consider the quality of the needs and targets developed and the sufficiency of the risk and opportunity identification. Part of the review should be a check of the scope and content against basic EM goals for the roadmap in general and, as applicable, for each need/target. Figure A-7 is a checklist template for the scope and content review.

After review, the developed needs should be documented for inclusion in the roadmap report and, as appropriate, summarized in the site STCG needs database and the needs management system component of IPABS.

Have the following been considered and included?

- ❑ Waste minimization
  - Primary waste steam
  - Side-stream wastes
- ❑ Long-term impacts
  - D&D considerations
  - Long-term stewardship considerations
- ❑ Overall system impacts
  - Total life cycle costs
  - Total life cycle health and safety risk impacts
  - Total life cycle schedule impacts
- ❑ Regulatory issues
  - Etc.
- ❑ State Agreement issues
  - Etc.
- ❑ Stakeholder issues
- ❑ Other site-specific issues
- ❑ Other program/project specific issues

Figure A-7. Roadmap scope and content review checklist template

Phase III: Technical Response Development

In Phase II, the cleanup problem-driven needs for science and technology development were established. In Phase III, the responses to those needs are mapped out. At this point, the focus shifts from the cleanup community and the capabilities needed, to the R&D community and the technologies to provide those capabilities.

Identify technology alternatives for targets

Development targets specify a capability or performance level, not a technology. In this step, possible technologies that could meet the development targets are identified. Brainstorming is used to identify all possible technical approaches. Then, a screening process reduces the alternatives to a manageable number.

To reduce the possibility of predetermining the outcome of the decision process, the screening methodology is developed before the candidate technologies are identified. Screening criteria include development time, development cost, and potential benefit, along with other problem-specific criteria such as maintenance costs and regulatory acceptance. The initial screening is based primarily on the expert opinion of the participants, not on rigorous analysis. The purpose is to limit the more detailed analysis of the next steps to only the likely alternatives.

Develop technical responses

A technical response is a proposed path forward to meet a need or target. For a roadmap, the technical response includes:

- Technical approach (including technology alternatives)
- Integrated activity logic
- Schedule (including decision points)
- Estimated cost.

Note that specifics such as fund sources and performing organizations are determined later during roadmap implementation.

Technical responses need to be well developed with care. A fully developed technical response is not just a list of possible R&D projects, but also a linked schedule and estimated budgets. For high-risk needs, the response should include initial development of multiple alternatives, along with ***decision points*** to narrow advanced development to only one technology. The decision points should be scheduled far enough into development that initial results can be used in the decision process, but early enough to limit R&D costs. How many alternatives to initially pursue, how much to invest, and when to make the "down select" decisions must be balanced against the importance of ensuring the needs are met. The completed response should include all activities necessary to reasonably ensure a full solution to the need.

Figure A-8 and Table A-2 are examples of technical response documentation from the SRS HLW salt processing alternatives roadmaps. Figure A-8 shows the development path logic for science and technology activities for the Small Tank TPB alternative. Table A-2 is part of the tabular summary for the technical responses related to this Small Tank TPB alternative.

At the program level, technical responses may be phased to coincide with near-term and long-term development targets. Incremental improvement of existing technologies will take place in parallel with basic research and initial development of breakthrough technologies. For long-term targets, the number of alternatives to pursue is based on the importance of meeting the needs. If the actual alternatives are not yet known by name,

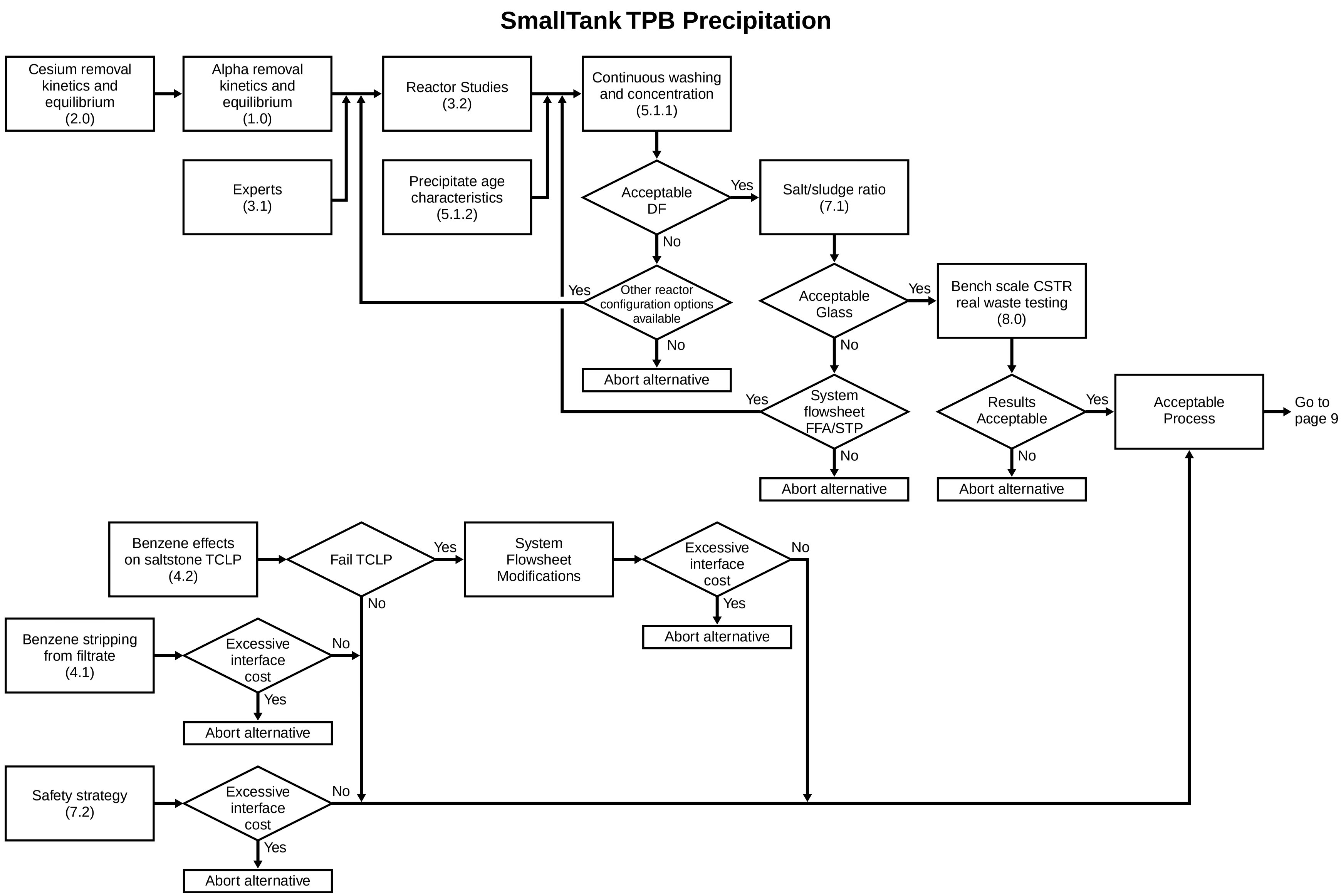

Figure A-8. Sample science and technology logic diagram showing development path logic from the CST Non-Elutable Ion Exchange roadmap

Work Scope Tasks Definitions

Group	Item	Type	Source	Req'd for Phase III	Considerations	Path Forward	Responsible Organization
Chemistry	7. Benzene generation at <25° is less than 0.7	Assumption	B, A & R	Yes	• Rates are critical to determining environmental releases • Excessive TPB decomposition reates could make process not viable due to frequency of re precipitation required to maintain DF.	• Conduct addition (simulant and radioactive tests at lower temperatures to understand benzene generation rates. (Simulant and Real Waste) • Testing started at risk. • Document low temperature tests (3200 hrs)	• SRTC • SRTC • SRTC
Chemistry	8. MST TRU removal reaches equilibrium in 24 hrs	Assumption	B, A & R	Yes	• Very little kinetic data available on MST adsorption kinetics. • Critical to proper sizing of SCTRs.	• Conduct tests to measure kinetics of MST decontamination for Pu, U, and Sr (SRTC)	• SRTC
Operations	9. Benzine deflagration in a processing tank will occur.	Risk	13.C.3-1	Yes	• Adequate safeguards are well understood and available.	• Document safety basis strategy.	• WSMS (Lead)
Operations	10. Recycle organics will negatively impact Tank Farm	Risk	13.A.3-4	Yes	• Treatment options to remove recycle organics should be studied, if warranted. Capital costs may increase. • Projected recycle and controls should be adequate. • Low priority – after down-select.	• See Item 1 • Complete studies if Small Tank ITP makes down-select or if material balances indicate need.	• See Item 1 • SRTC
Chemistry	11. Benzene geration equals release	Assumption	B, A & R	No	• Good mixing required to validate assumption. • Smaller volumes result in good mixing characteristics.	• Complete during design.	• NA
Safety/ Regulatory	12. DNFSB 96-1 issues cannot be closed	Risk	13.C.10-1 Team	Yes	• Design of facility would remove requirements for some concerns.	• Document Filtrate Test. (High Level Caves filtrate) • Revise Document on Excess NaTPB Decomposition. (3200 hrs) • Document Safety Strategy.	• SRTC • SRTC • WSMS (Lead)
Engineering	13. Fresh Precipitate rheology will provide more stringent transfer reqirements	Risk	Flowsheet/ Chemistry	No	• Pumping of fresh precipitate will be more difficult. • Existing rheology data adequate to complete design.	• Verify during design.	• NA
Operations	14. Operation of Mercury Purification Cell and transfer not proven	Risk	Outside Expert	No	• Mercury primarily a sludge concern. Mercury from salt process insignificant.	• None	• NA
Operations	15. Addition of antifoam will have deleterious effects on down stream processes	Risk	Flowsheet/ Chemistry	Yes	• Surfynol 420 has been studied for use in the Late Wash process. • The impacts on the levels of Surfynol expected from this process on DWPF have been determined.	• Add surfynol to the material balances and determine if the amount fed to DWPF is within the bounds previously studied.	• Flowsheet Team
Engineering	16. Initial flowsheet did not contain filter cleaning facilities	Risk	Flowsheet Team/SRTC	Yes	• Filter cleaning will be required	• Add facilities for filter cleaning to flow sheet.	• Flowsheet Team

Table A-2. Sample work scope task definitions from the SRS HLW roadmap for small tank TPB precipitation.

placeholders, such as "New Technology 1," "New Technology 2," are used (for example, see Figure 2B). The number of new technologies identified will guide the allocation of research funding.

For all technical responses, the rate of technical maturity must be mapped to indicate the pace necessary to achieve the development target. This will guide the R&D program managers in R&D project solicitation, selection, and progress reviews. This can be done by relating the development path schedule to gates in the DOE Office of Science and Technology (OST) Technology Maturity ***Gate Model*** indicating, for example, when completion of Gate 4 (the transition into "engineering development") is expected. Progression through the technology maturity gate model on the target pace will also assure the cleanup project manager that the R&D activities are on schedule.

Prioritize needs and responses

The needs identification and response development process will typically identify more R&D than can be achieved with available resources. Final prioritization by the roadmapping team provides a consensus view of the most important needs. The associated resource requirements guide resource allocation. Prioritization is done at the technical need and response level, not at the individual activity level within a technical response. (Prioritization at the activity level results in the development of partial solutions, which are difficult to use.)

As with the screening step conducted earlier in this phase, the methodology for prioritization needs to be explicitly defined, established prior to application, and consistently employed. Prioritization is a key part of the roadmap documentation process. A total base R&D budget is assumed. The final prioritized list indicates those technical responses to be included in the integrated schedule.

Develop integrated schedule

At this point in the process, the prioritized technical responses are combined into an integrated schedule. The schedule includes identification of all R&D activities shared by more than one technical response. Individual response schedules are adjusted to remove any duplication of effort. At the project level, the resulting R&D activities schedule is integrated with the balance of the project schedule.

The schedule is developed in graphical form and accompanied by a table describing each activity and its objectives, cost, schedule, and interfaces. A summary budget is developed indicating needed allocations by year.

Figures A-9 and A-10 are examples of project- and program-level integrated schedules from SRS and Hanford. Note that the project-level schedule in Figure A-9 is driven by initiation of facility construction, while the program-level schedule in Figure A-10 is organized around development of base system assessment capabilities and support to core projects.

Create the roadmap report

The roadmap report and backup material are the primary products of the roadmapping effort. A typical report includes the following sections:

- Executive Summary
- Introduction and Background
  - Mission/project goals, objectives, and end states
  - Scope and boundary conditions of the roadmapping effort
  - Relevant constraints (regulatory, stakeholder, budget, etc.)

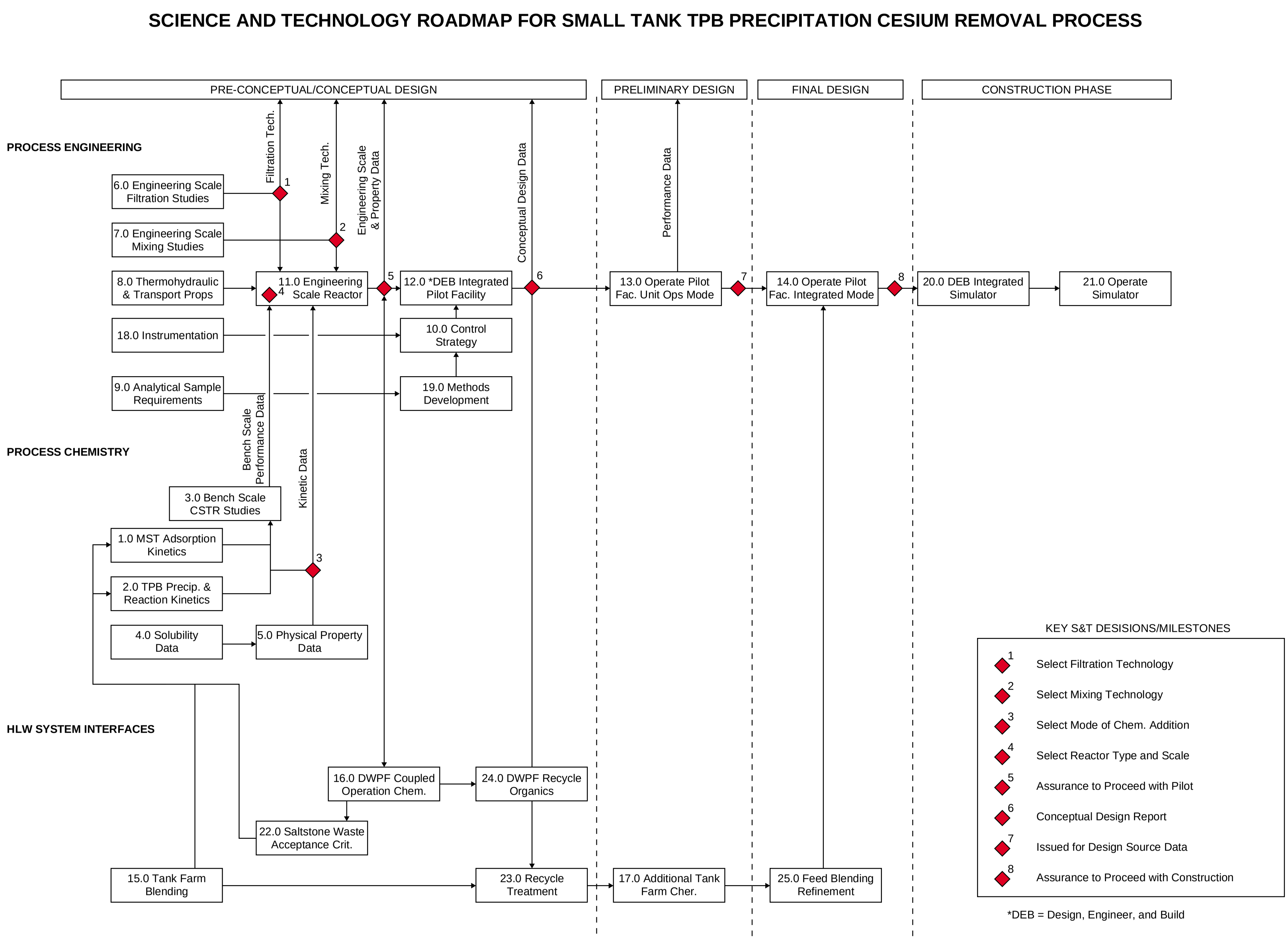

Figure A-9. Sample summary schedule from SRS HLW Project-Level Roadmap

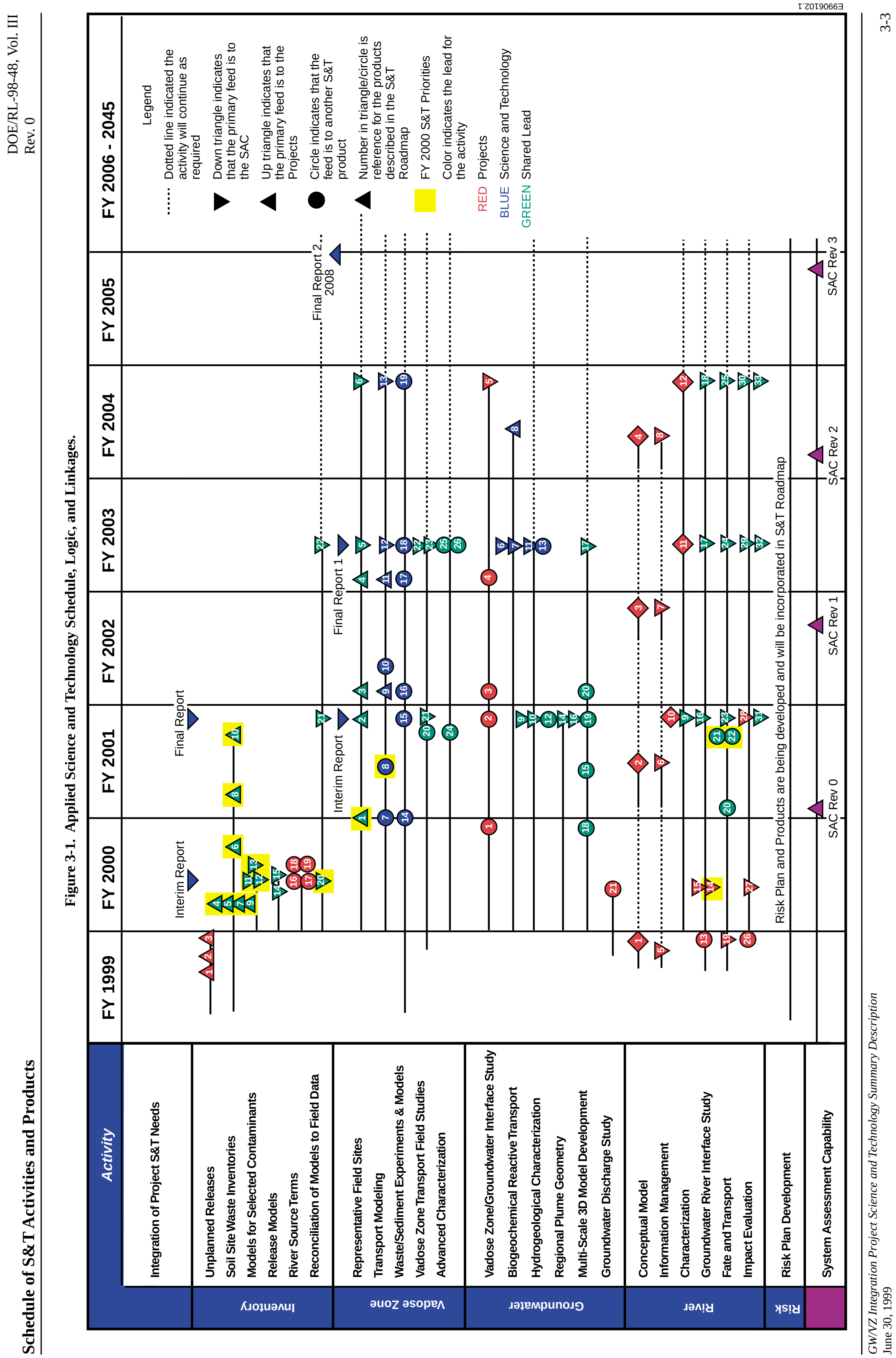

Figure A-10. Sample summary schedule from Hanford GW/VZ Program-Level Roadmap

- Technical Needs and Capabilities
  - System flowsheets
  - Functional and performance requirements (programmatic, technical, etc.)
  - Current science and technology capabilities
  - Existing gaps and barriers
  - Development strategy and targets
- Technology Development Pathways
  - Evaluation and prioritization criteria
  - Recommended technical responses
  - Decision points and schedule (activities, sequencing, and interfaces)
  - Budget summary
- Conclusion
  - Summary recommendations
  - Implementation path forward
- Appendices
  - Roadmapping process
  - Participants
  - Technical response activity description tables

For larger roadmaps or roadmaps with high political visibility, the executive summary can be a separate report or volume. This summary provides details of the entire roadmap process including findings, recommendations and priorities for alternative technology selection, and the recommended path forward.

Phase IV: Roadmap Implementation

In Phase IV, the roadmap report is reviewed, released, and implemented. This phase begins with management briefings on the roadmap findings, independent technical reviews, and report finalization. After release of the roadmap report, implementation plans are developed, T&D budgets allocated, and R&D work plans executed. Implementation progress is tracked and the roadmap report revised and updated as needed.

Review, validate, and publicize the roadmap

A multidisciplinary team representing the primary organizations involved in the project or program prepares the roadmap. After the team completes the draft, it is distributed to a broader internal group for review. The review has two purposes. First, the broader group validates the results of the roadmapping effort. Second, it initiates the process of publicizing the roadmapping recommendations.

An independent review by a blue ribbon committee is recommended for program-level roadmaps and high-visibility project-level roadmaps. The committee may be formed just to conduct the review, or an existing organization such as the National Academy of Science may be asked to conduct the review. If an independent review is called for, the review should be conducted in stages during roadmap development.

Review comments are collected, and responses prepared and issued. The draft report is finalized, endorsed by the sponsor, and published. It is then distributed to all participants, management, and other interested parties.

Depending on the level of the roadmap, briefing of findings are provided to the DOE field office or DOE Headquarters. Large roadmapping efforts also should issue press releases, newsletters, or other forms of communication.

Develop an implementation plan

The roadmap document is a strategic plan for the R&D supporting a project or program. After the roadmap is approved and published, an implementation plan is prepared. The implementation plan includes specific, near-term activities and budgets, and longer-term resource projections. Implementation plan development should include the following considerations:

- Development of a communication and reporting plan
- Determination of the budget allocations to various alternatives, tasks, and issues
- Where diverse multi-laboratory participation is involved, development of a management plan with associated accountability, change controls, requirements, etc.
- Where multiple alternatives are involved and a decision will be required, criteria for the “down selection” decision to one alternative should be finalized prior to initiating work (This allows the work on each alternative to address the criteria and the associated issues requiring resolution.)
- Agreed on methodology for managing risk and changes in risk as progress is made, since risk will be a key element in future decisions.

During execution of the plan, the cleanup project/program manager champions R&D funding and monitors progress by the R&D organization.

Figures A-11 and A-12 are examples of implementation planning from the Robotics and Intelligent Machines (RIM) roadmap. The RIM roadmap is an example of a ***critical or emerging technology*** roadmap, another type of science and technology roadmap used for DOE-wide planning.

Review progress and update plans

A roadmap is a living document. As implementation proceeds, the roadmap is periodically reassessed, especially if the supported cleanup program or project undergoes major changes or the results of the R&D activities are not turning out as expected. Project-level roadmaps and implementation plans become an integral part of the project baseline, and are modified as needed through the project's change control and document management processes. For a program-level roadmap, a formal update is conducted within 5 years or a third of the way through implementation, whichever comes first.

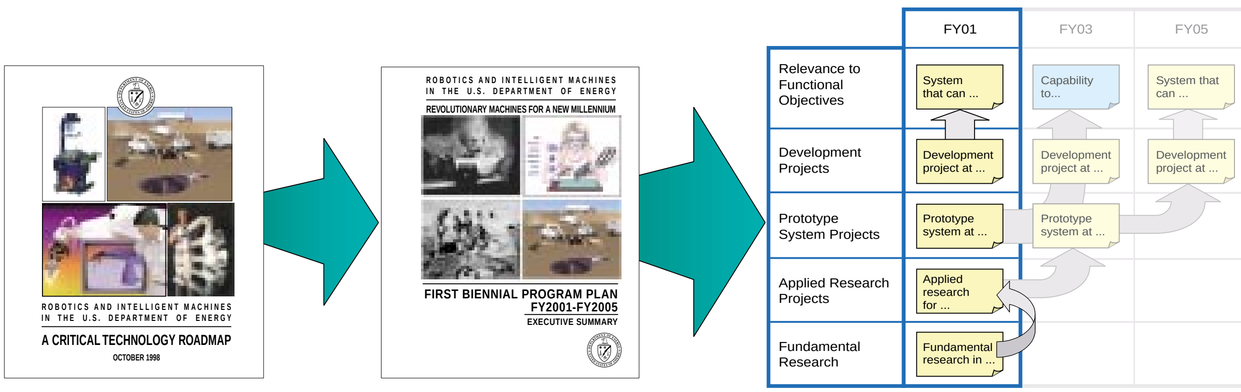

Figure A-11. Example of implementation process from Robotics and Intelligent Machines (RIM) roadmap

Project Title:	Modular and Reconfigurable Manipulator Systems
Description:	Develop new families of robot joint actuators suitable for telerobotic systems in the payload ranges associated with D&D tasks. Advanced materials and fundamental actuation principles will be incorporated to achieve an entirely new generation of robot actuators. This project will also develop a theoretical basis for mapping task geometry and force requirements and constraints into manipulator joint/link sequence configuration requirements.
Functional Objectives:	Reduce personnel exposure and hazards; Increase productivity
Stage of R&D:	Gate 1
FY01 Project Costs:	$950K
Life of Project Costs:	$10M
Delivery Date:	Generation I, FY05
Customer:	EM- D&D

Figure A-12. Sample task description from Robotics and Intelligent Machines (RIM) Critical Technology Roadmap implementation documentation

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